

## **Failure Analysis in Space: International Space Station (ISS) Starboard Solar Alpha Rotary Joint (SARJ) Debris Analysis**

V.L. Salazar, M.C. Wright, S.J. McDanel, D.L. Lubas, B.P. Tucker, P.J. Marciniak <sup>1</sup>

<sup>1</sup> *National Aeronautics and Space Administration, Kennedy Space Center, USA;*

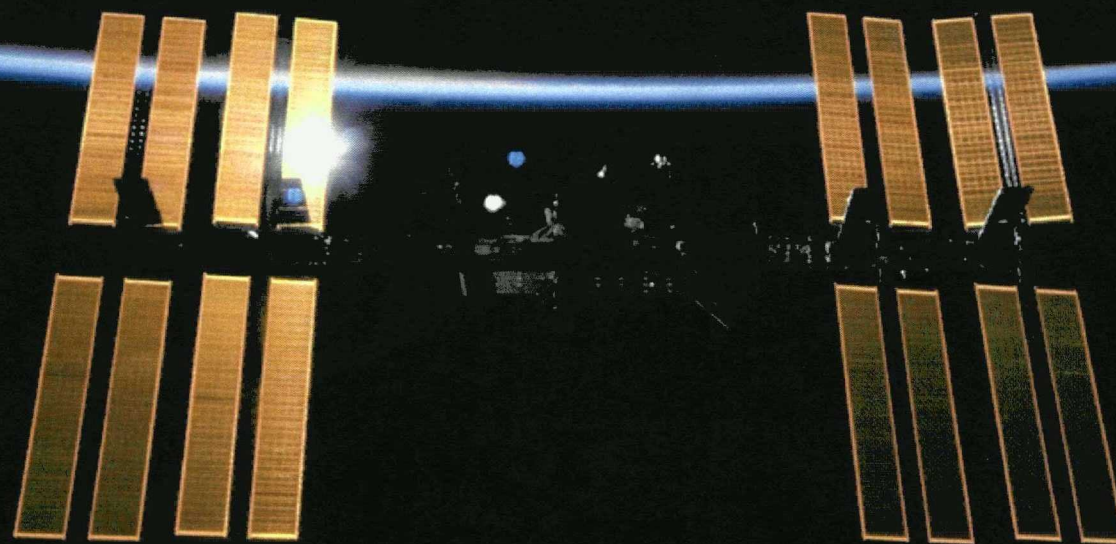
E-mail: *Victoria.L.Salazar@nasa.gov*

Space Shuttle mission STS-117 delivered the S3/S4 truss segment to the ISS, which included a SARJ that rotates 360° to position the solar arrays facing the sun. Three months after installation, vibration was observed in a camera mounted on the SARJ, and an investigation commenced to find the source. Debris was collected from the starboard SARJ during an extra-vehicular activity (EVA) of STS-120 and returned to the Kennedy Space Center so that a remote failure analysis could be performed on Earth. A plan was formulated to identify the source of the debris and to determine the failure mechanism. This presentation will show the data from the analysis—including stereomicroscopy, scanning electron microscopy, energy dispersive spectroscopy, and laser confocal microscopy—and interpret the data in support of the failure analysis. The debris originated from the race ring and failure of the fragments appeared to be the result of contact stress fatigue.



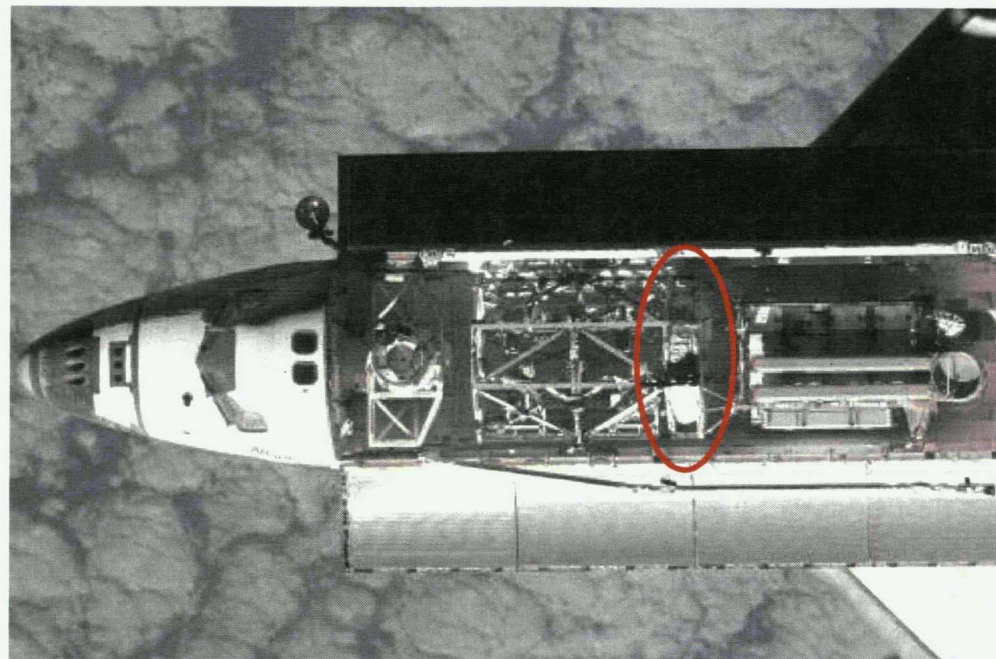
# Failure Analysis in Space

International Space Station (ISS) Starboard Solar Alpha  
Rotary Joint (SARJ) Debris Analysis



V.S. Long, M.C. Wright, S.J. McDanel, D.L. Lubas, B.P. Tucker, and P.J. Marciniak  
National Aeronautics and Space Administration  
Kennedy Space Center, FL



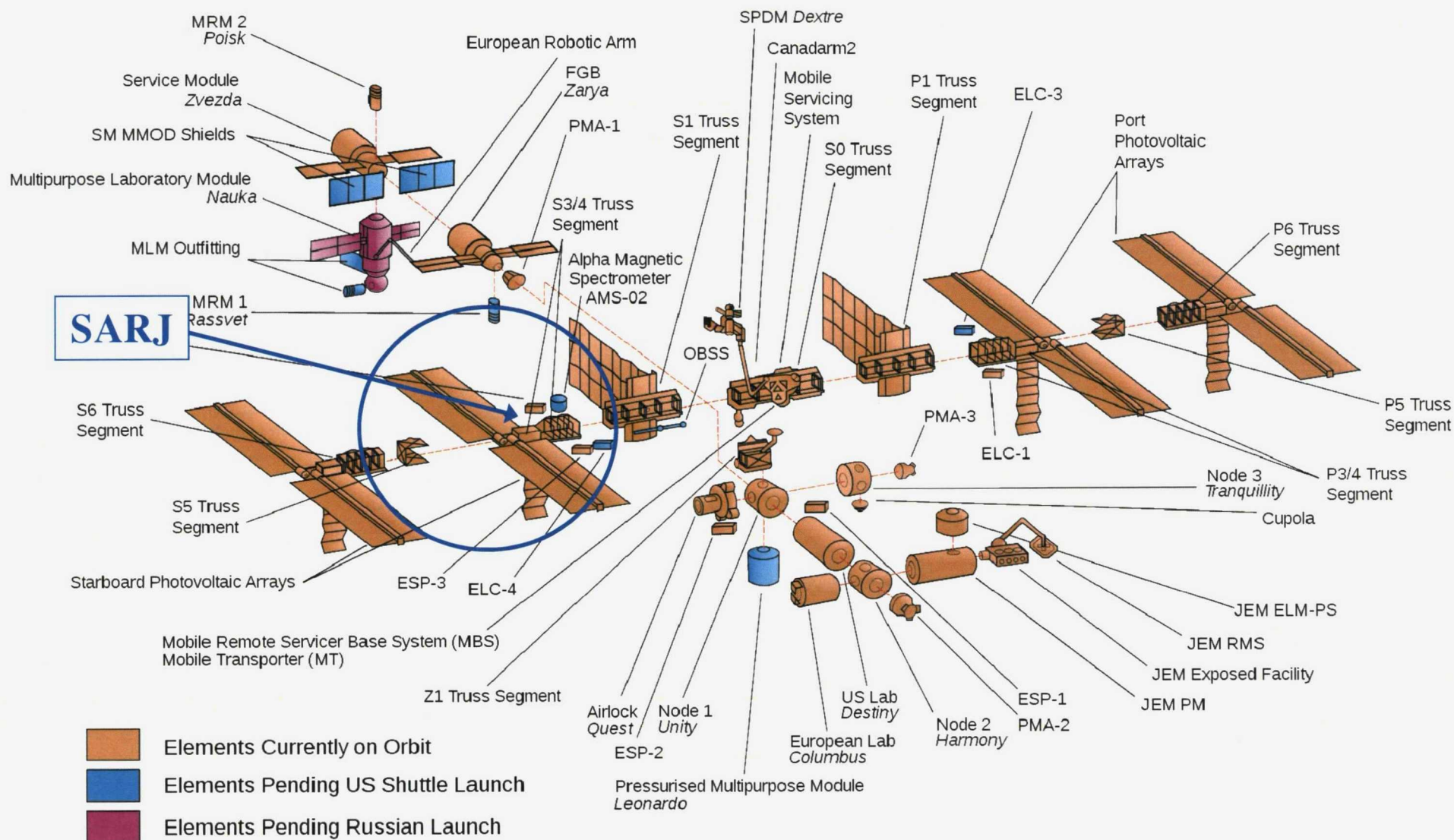






## KSC Engineering Directorate Materials Science Division

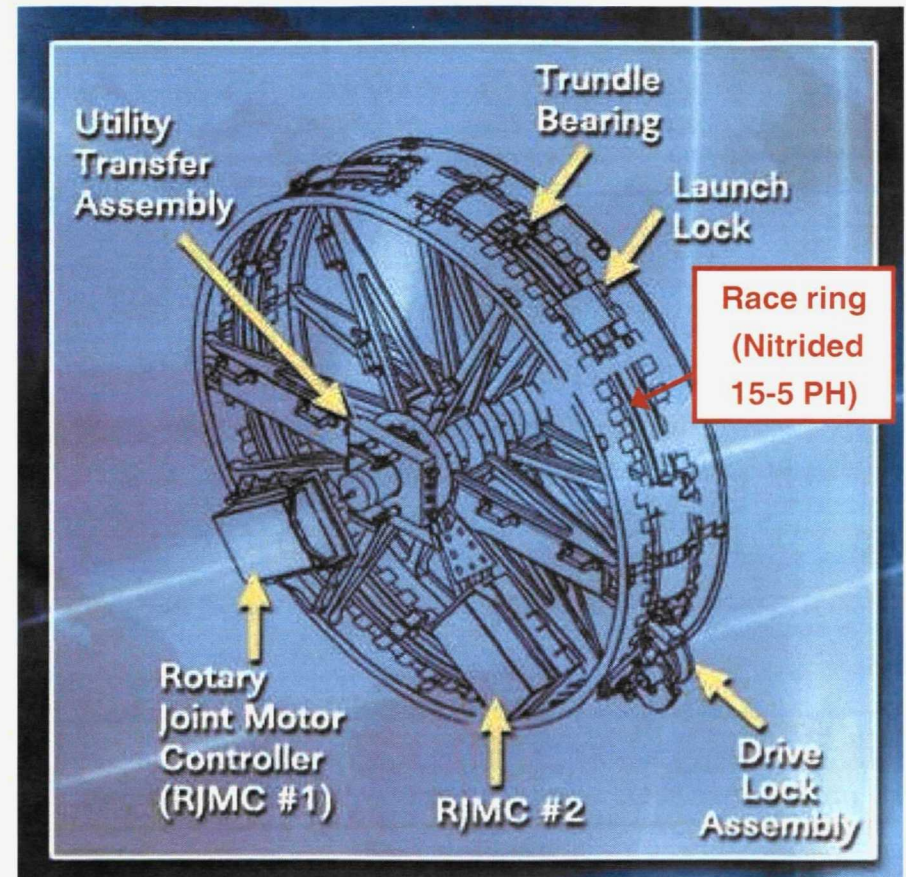
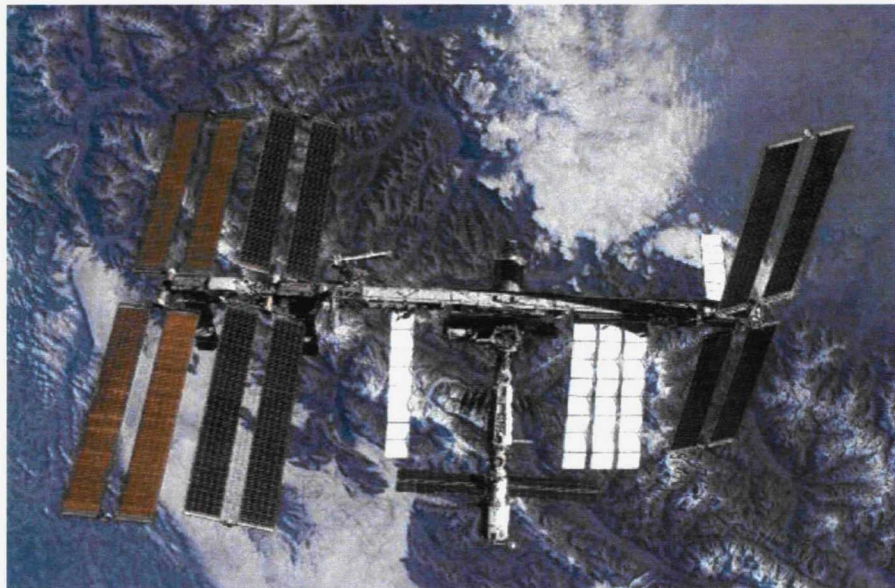
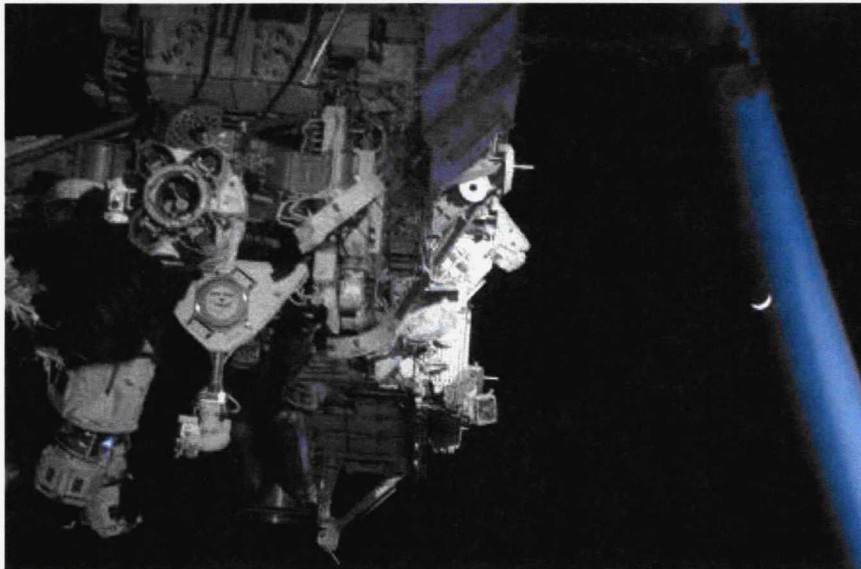
## ISS Assembly







## Solar Alpha Rotary Joint (SARJ)



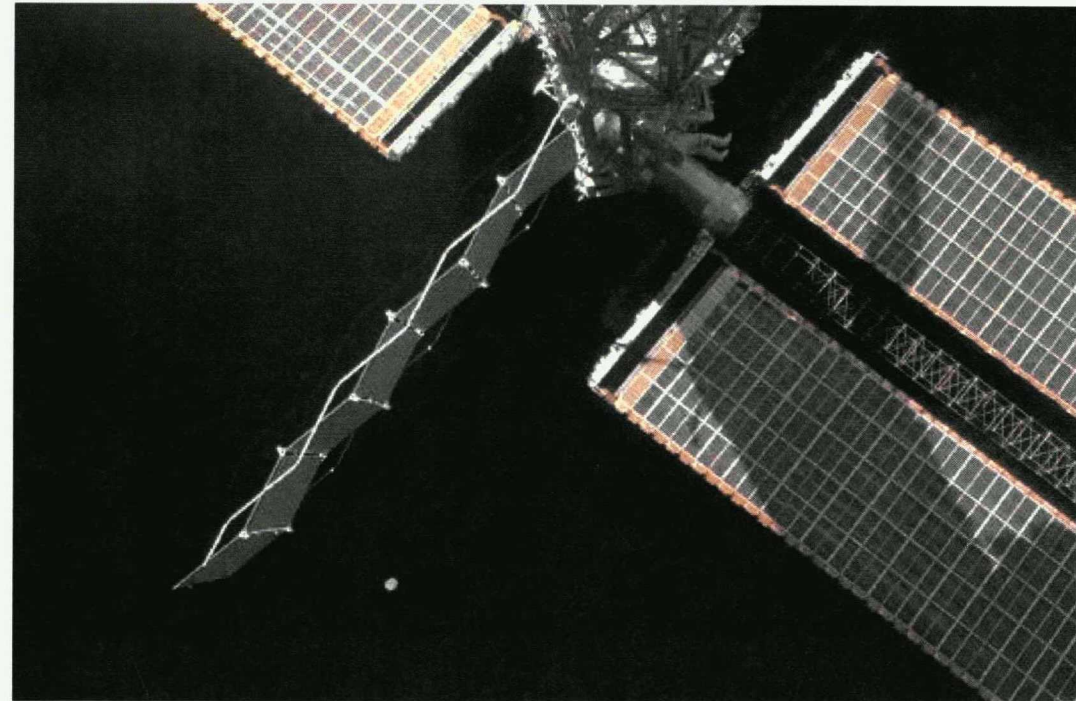
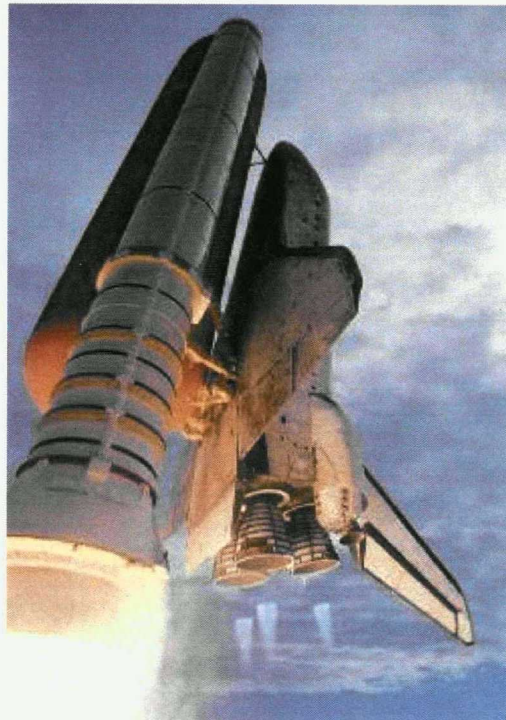
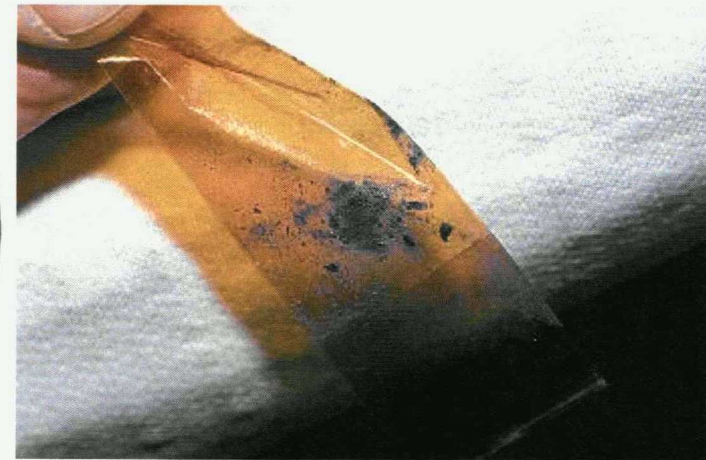
The SARJ is 10 feet in diameter and rotates 360° in order to keep the solar arrays facing the sun.





KSC Engineering Directorate  
Materials Science Division

STS-120, October 2007







- A plan was developed to identify the failure mechanism based on surface morphology and to determine the source of debris through elemental and particle analysis.
  - Perform photodocumentation and stereomicroscopy.
  - Conduct baseline studies on reference materials.
  - Perform initial SEM/EDS analysis.
    - Variable pressure mode.
    - Backscattered electron detector.
  - Remove several fragments from the tapes and examine via SEM.
  - Mount and cross-section several fragments for metallographic analysis.
  - Perform microhardness tests on the mounted fragments.

Solar Alpha Rotary Joint (SARJ) Materials

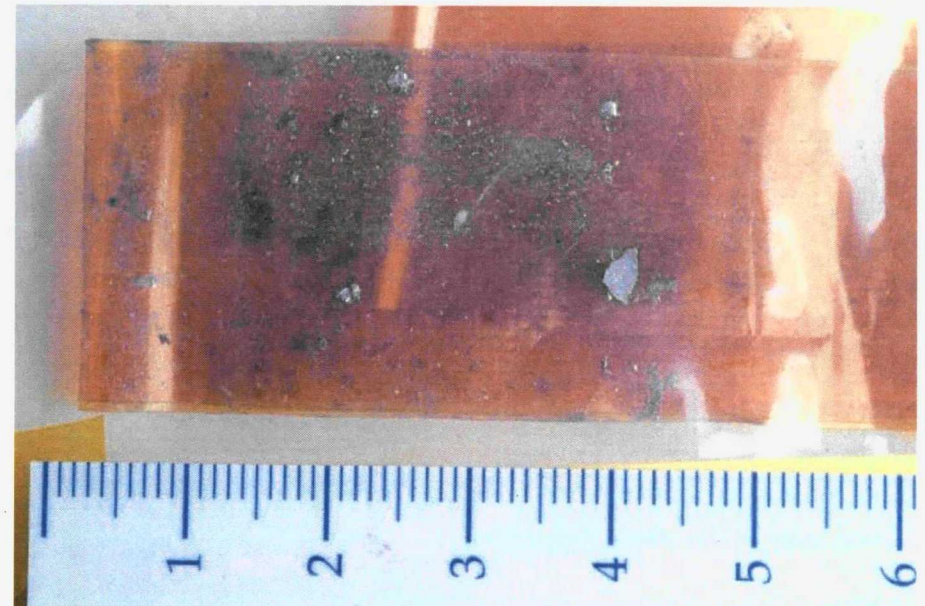
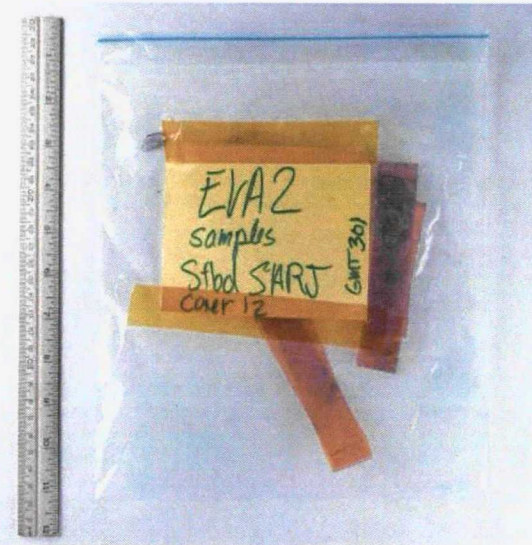
Location	Plating	Material	UNS	C	Mn	Cr	Ni	Fe	Mo	P	S	Si	N	Al	Cu	Nb + Ta
Primary Ring		Nitrided 15-5 PH	S15500	.07 max	1.0 max	14-15.5	3.5-5.5	bal		0.04 max	0.03 max	1.0 max			2.5-4.5	0.15-.45
Rollers	Gold	440C	S44004	0.95-1.20	1.0 max	16-18		bal	0.75 max	0.04 max	0.03 max	1.0 max				
Pinnions	Gold	13-8Mo	S13800	0.05 max	0.1 max	12.25-13.25	7.50-8.50	bal	2.0-2.5	0.01 max	0.008 max	0.1 max	0.01 max	0.9-1.35		
Centering Spring	Ni-P	17-7 PH	S17700	0.09 max	1.0 max	16-18	6.5-7.75	bal		0.04 max	0.03 max	1.0 max		0.75-1.5		

Table 1. Potential Debris Compositions, wt.%. Highlighted boxes indicate the constituents that vary significantly between the expected alloys in the SARJ.

Source: ASM Handbook Vol. 1



- Following landing and de-stow, samples were delivered to the Materials Failure Analysis Laboratory.
- Three sample tapes were received for analysis and were photographed, as-received.
- Initial analysis was performed overnight.





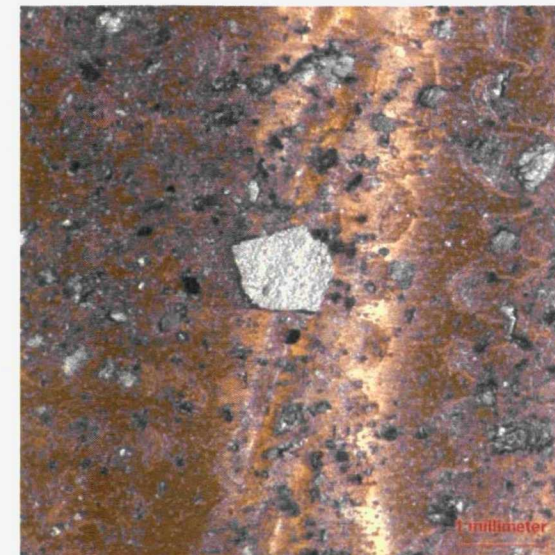


Representative particles from the tapes.

6.3X

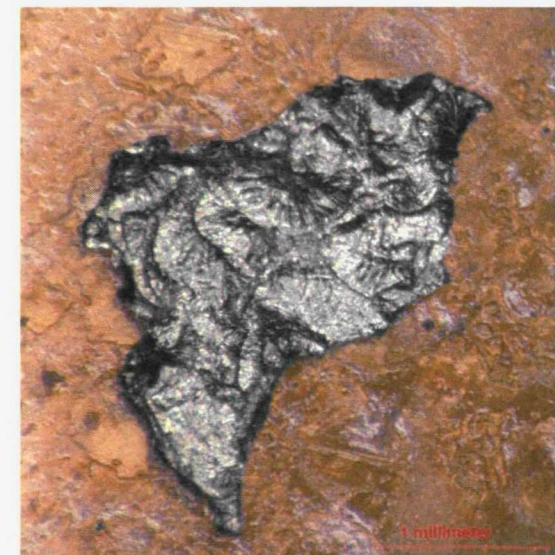
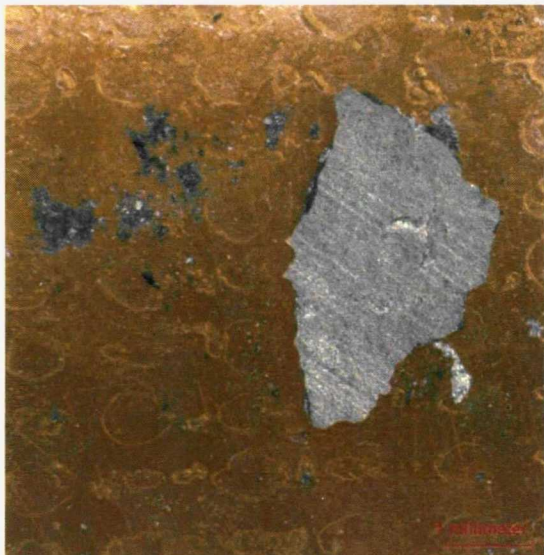


- Wide particle size distribution.
- Distinct particle morphologies.
- Scale bars are 1mm.



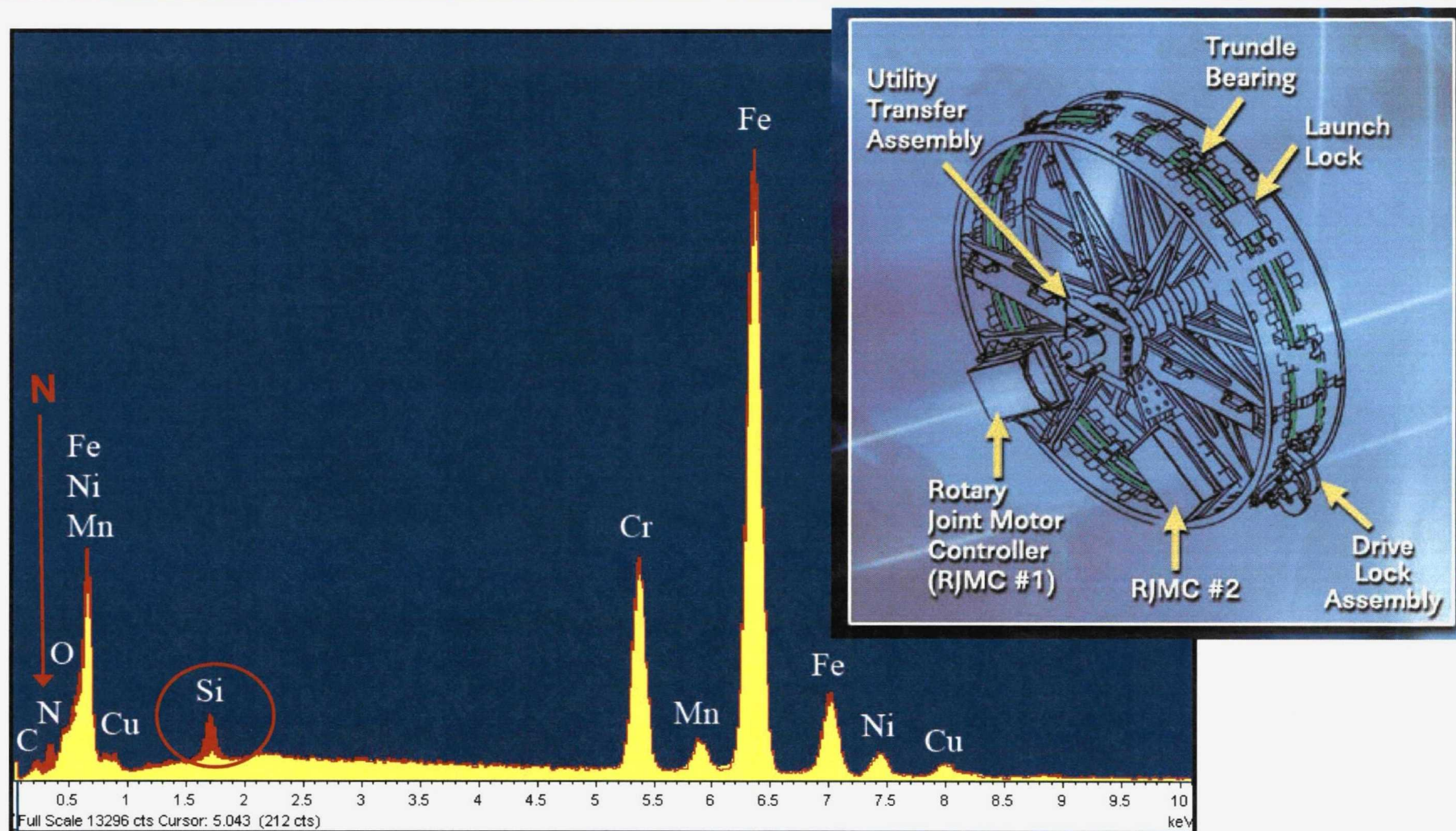
20X

20X



40X

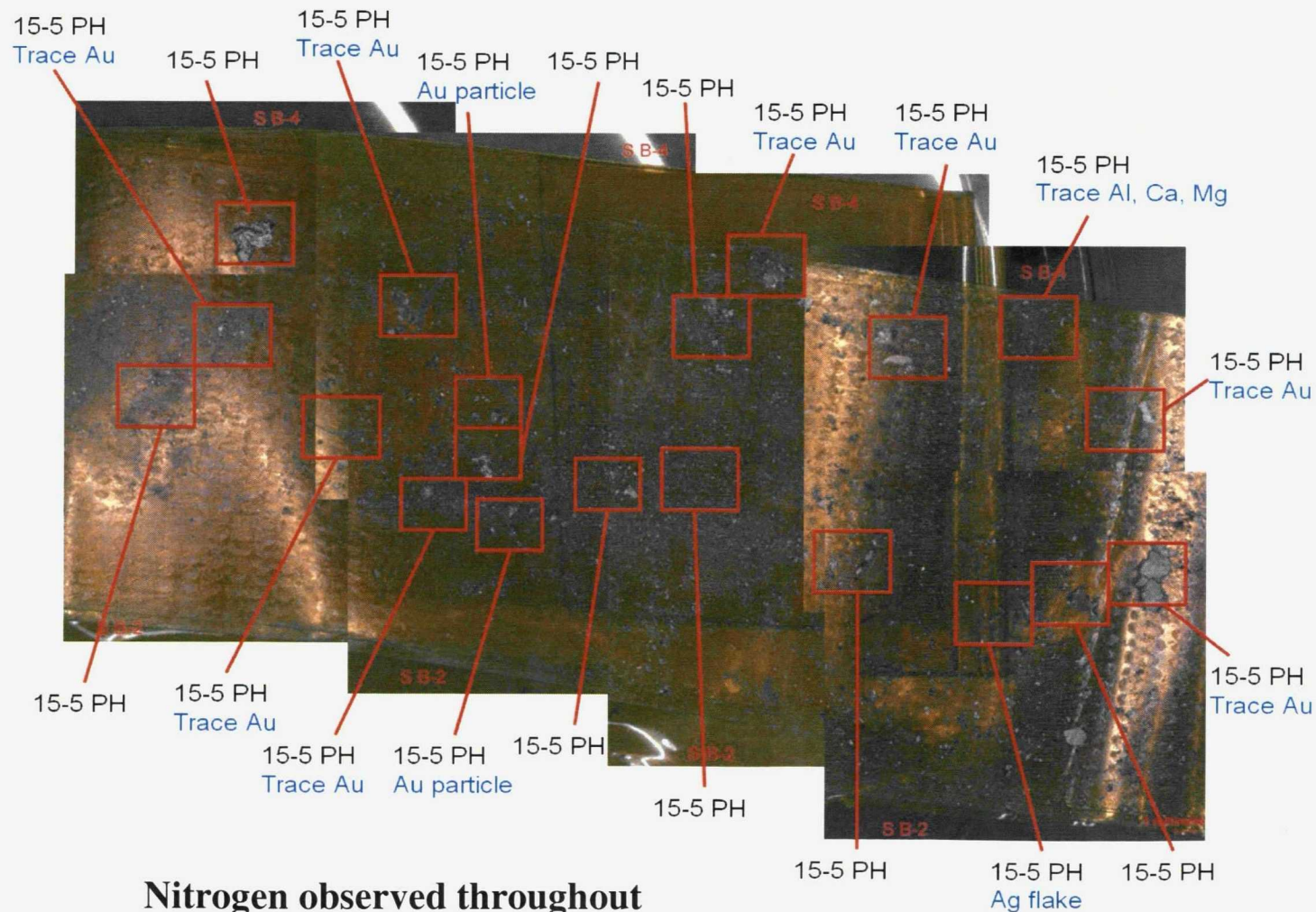




Overlay of representative spectrum from debris (red) on the baseline 15-5 PH spectrum. Nitrogen peak indicates that the debris is from the nitrated layer. The silicon peak is from the silicone adhesive used on the sampling tape.

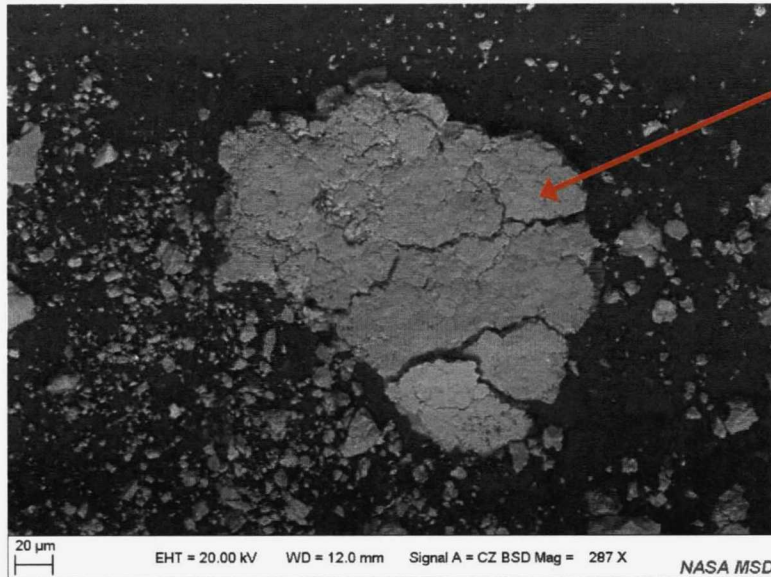


Representative tape showing the analysis locations. The majority of the particles were nitrided 15-5 PH stainless steel.

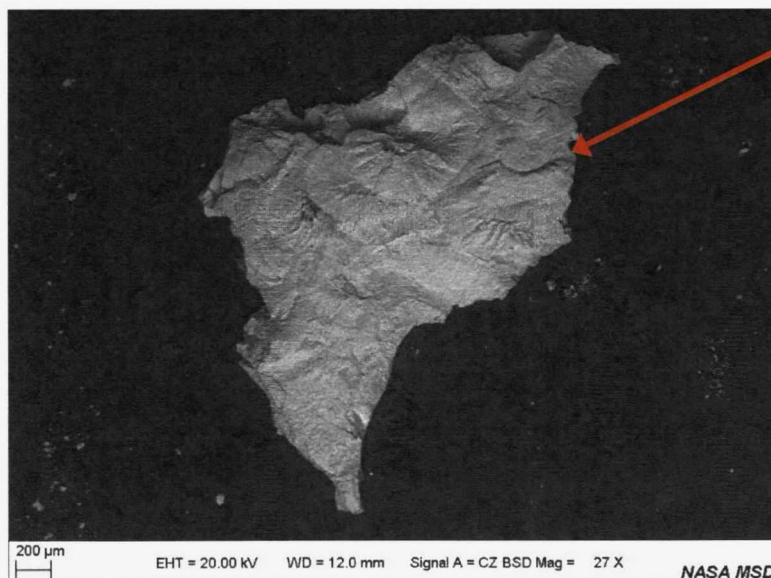
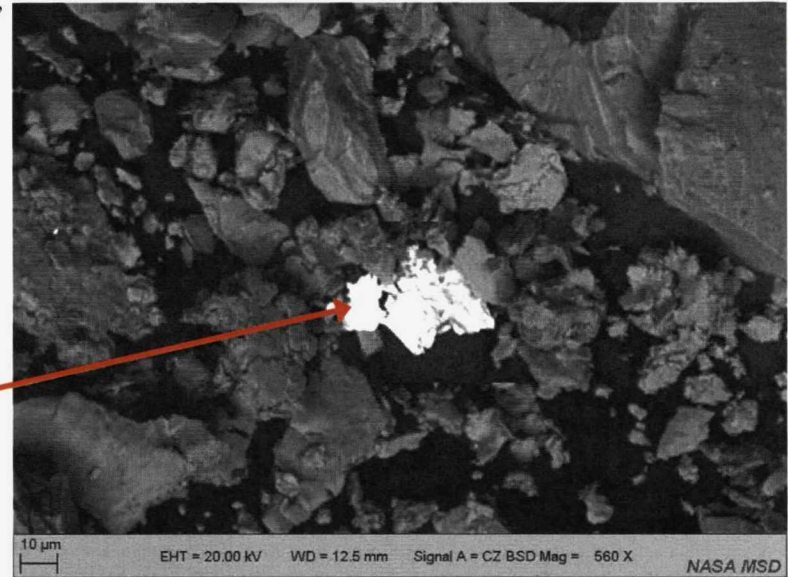




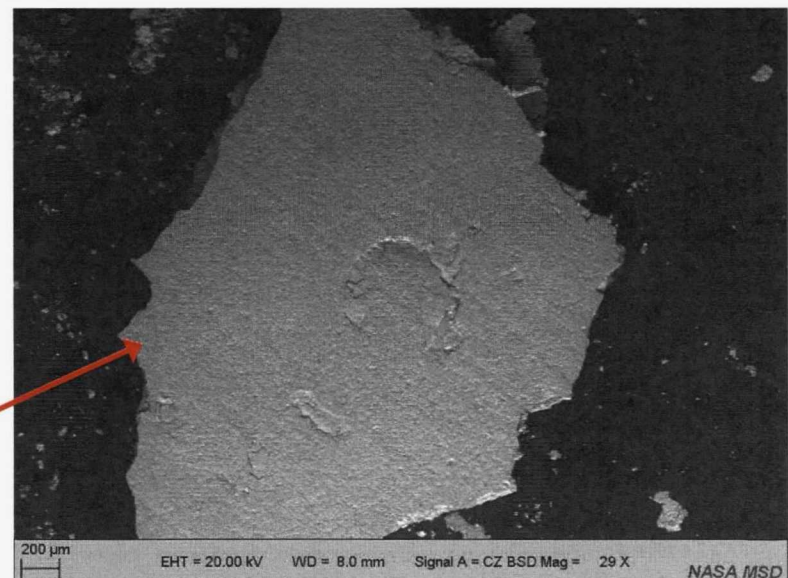
## SEM Images of SARJ Debris



Gold particle  
showing  
atomic  
contrast.



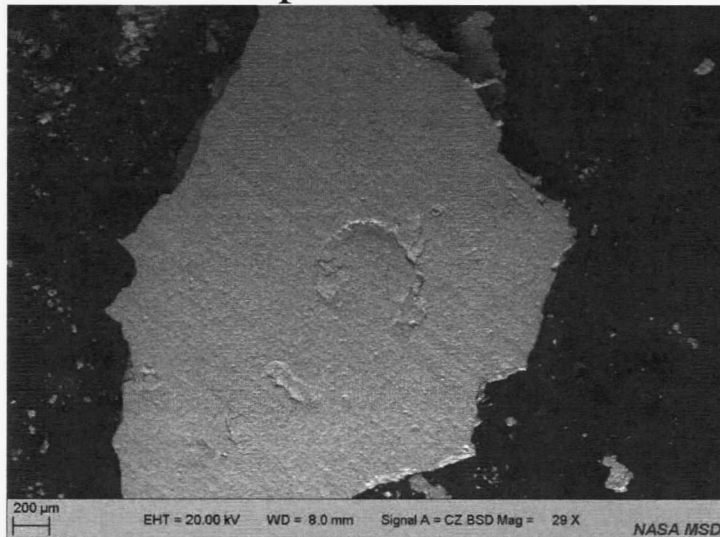
Original 15-5  
PH nitrided  
surface with  
machine  
markings.







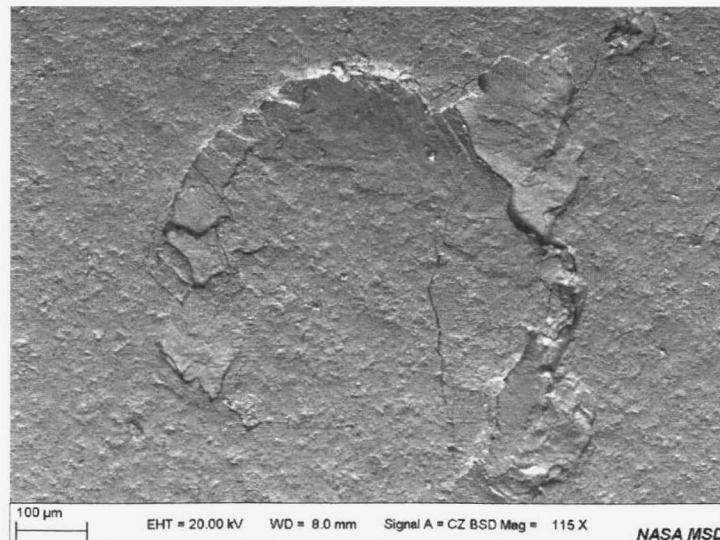
Obverse of particle



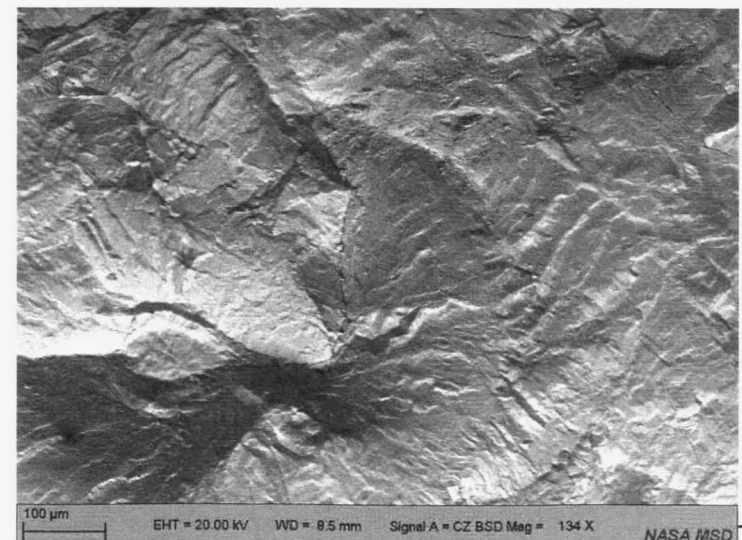
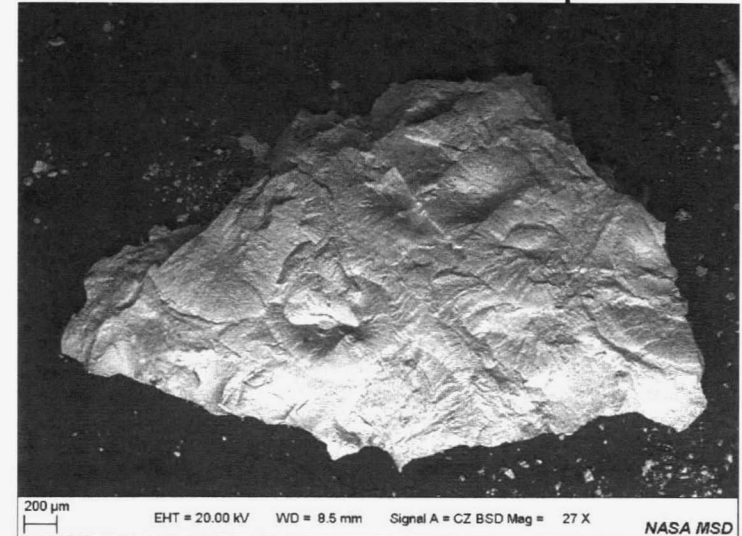
Flipped and rotated



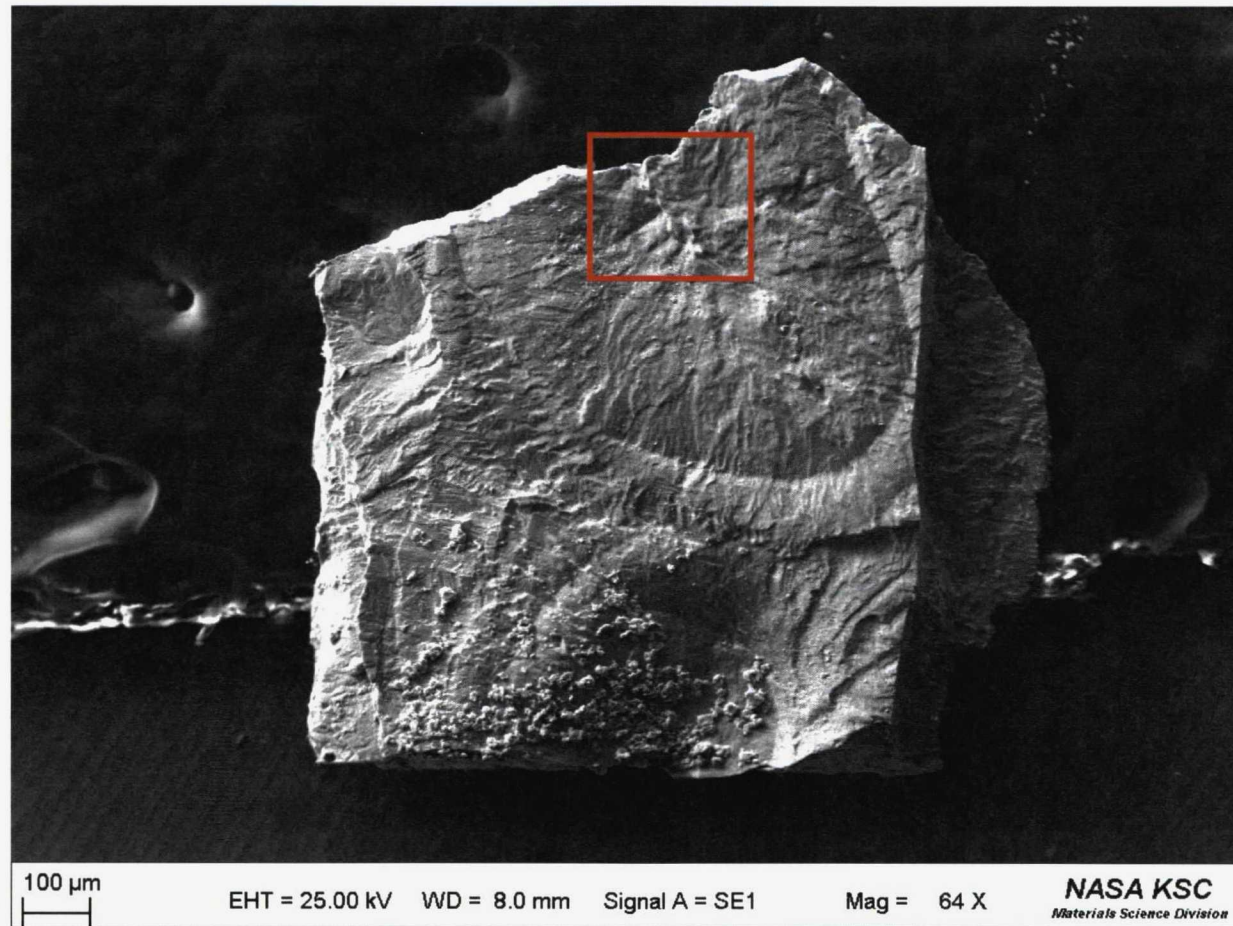
Nitrided 15-5 PH  
surface with  
machine markings  
on obverse (L)  
and flipped over  
revealing  
scalloped reverse (R).



Reverse of particle



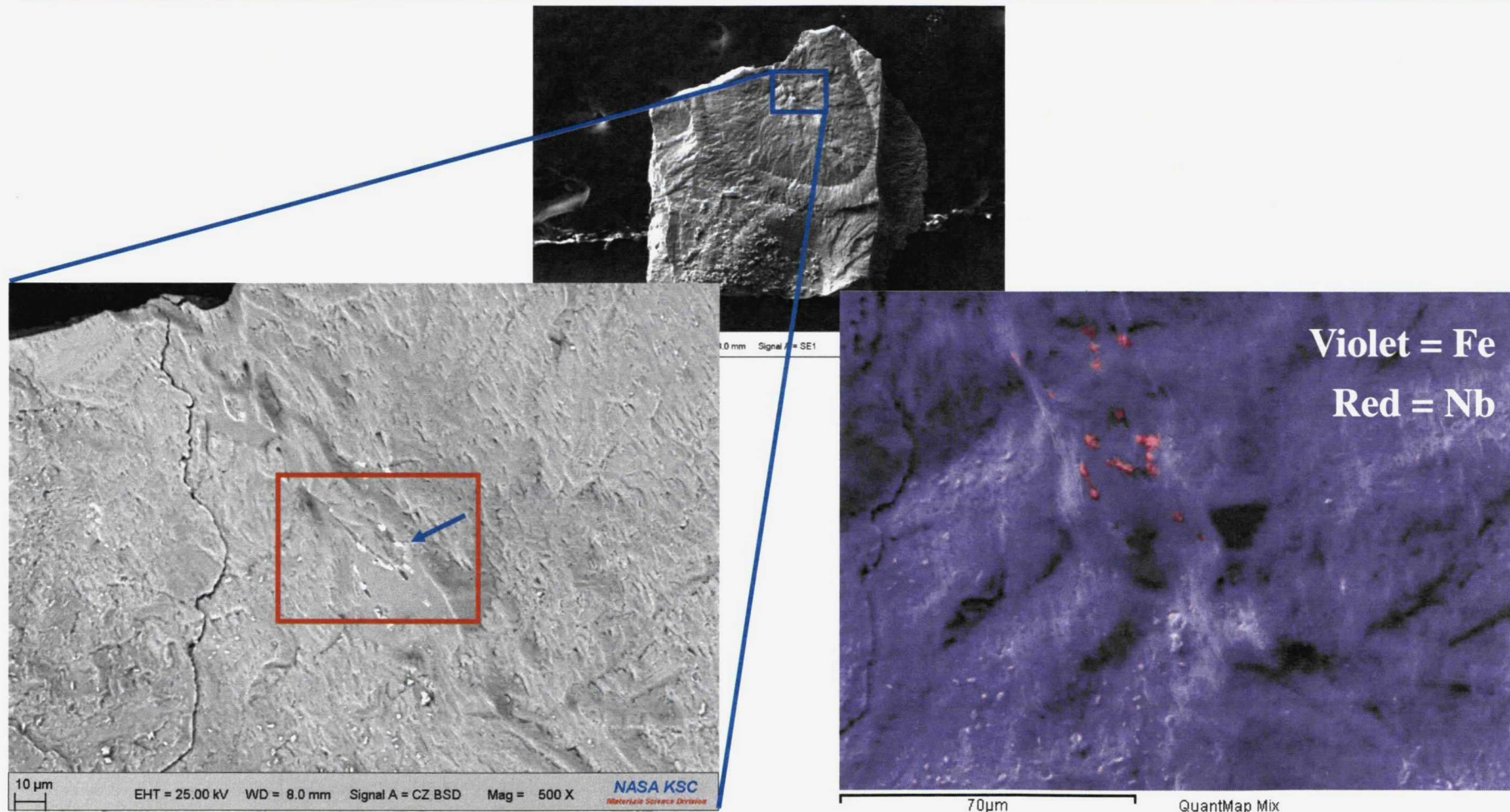




Secondary electron (SE) SEM image of a fragment removed from tape and imaged under high vacuum.

Area in red box appears to be a fracture initiation site and elliptical region suggests crack arresting. Features typical of spalled fragments.

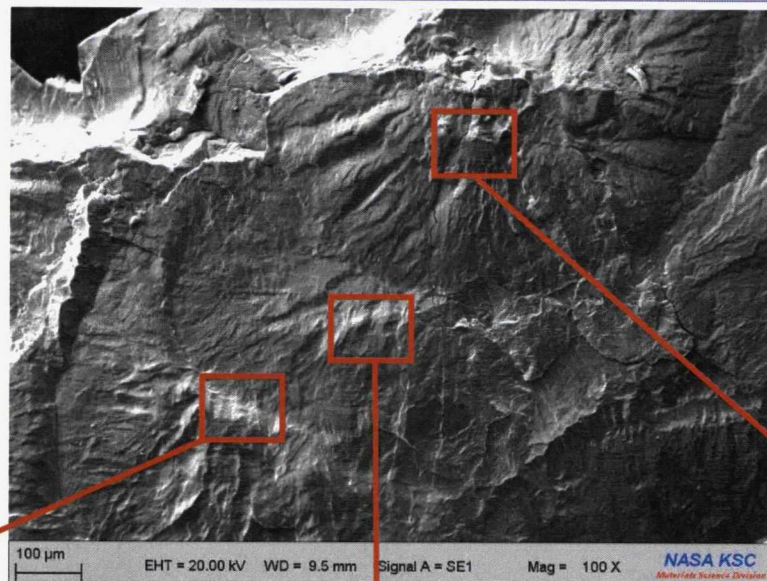




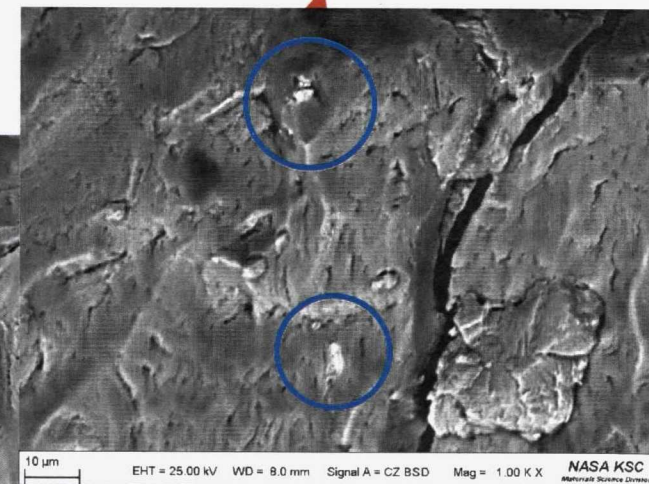
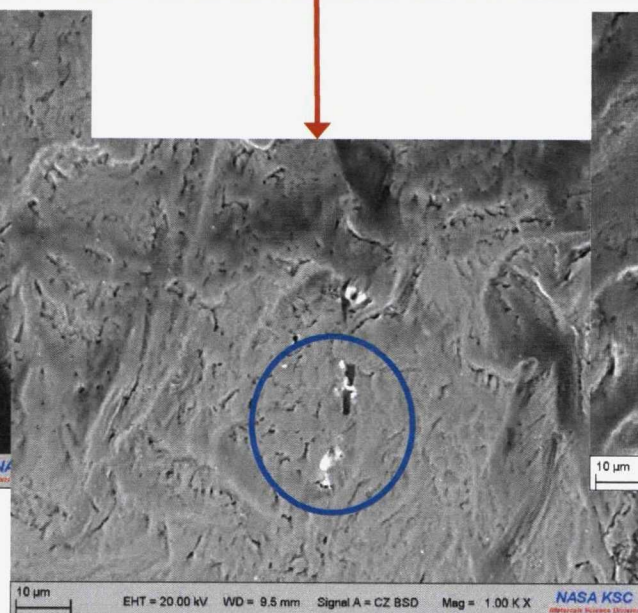
Backscattered electron image of outlined area in red box from previous slide showing atomic contrast.

X-ray elemental dot map of the boxed area, showing niobium-rich precipitates in an iron-rich matrix.

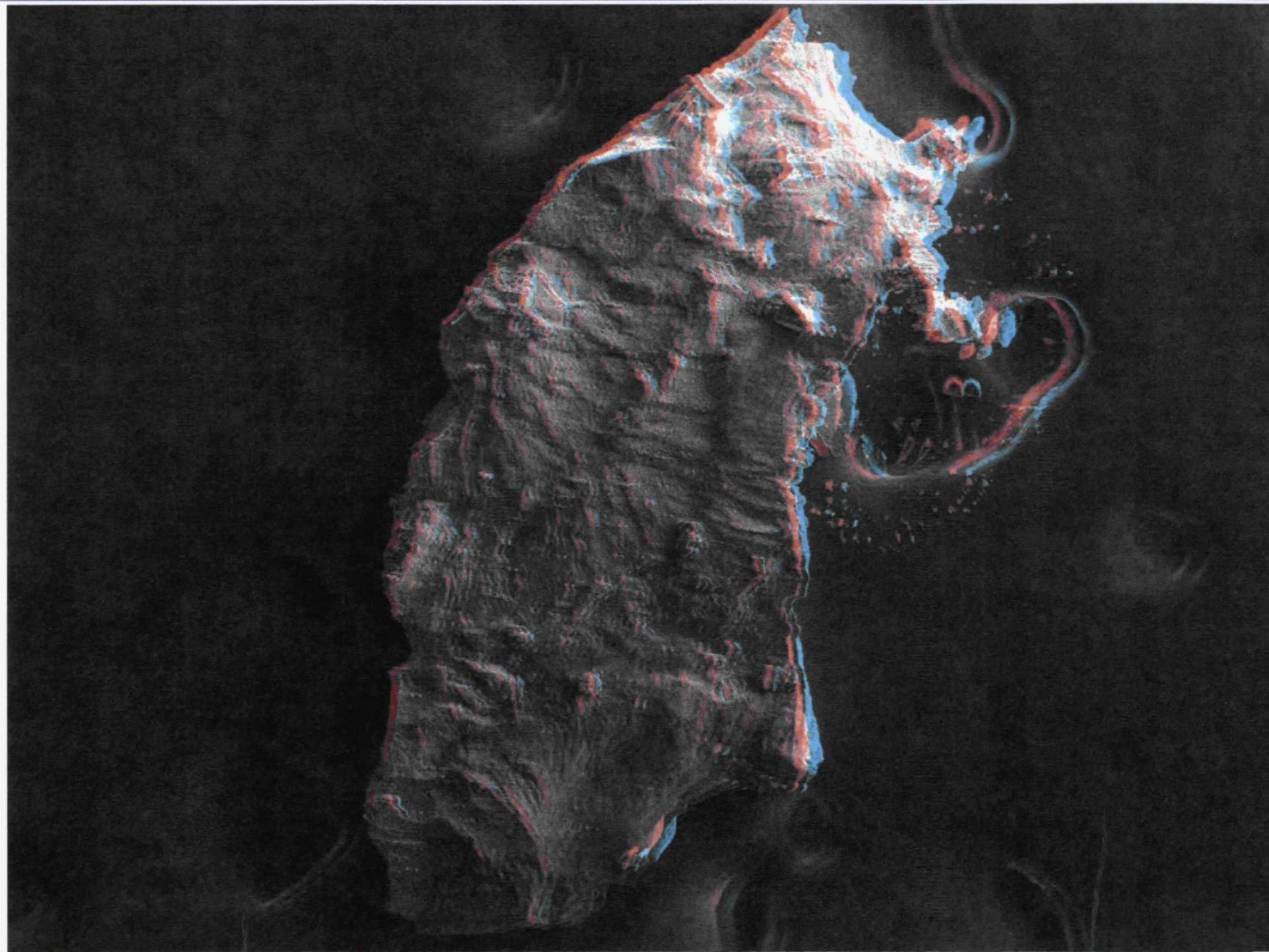




Backscattered electron image showing atomic contrast of the niobium-rich precipitates at typical subsurface fracture initiation sites.





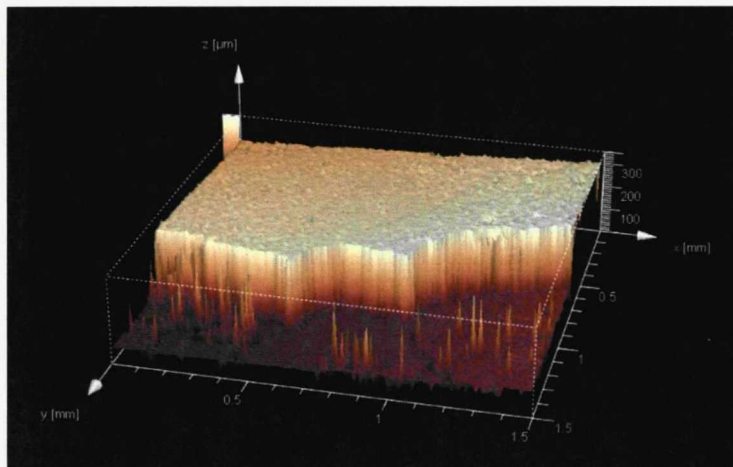
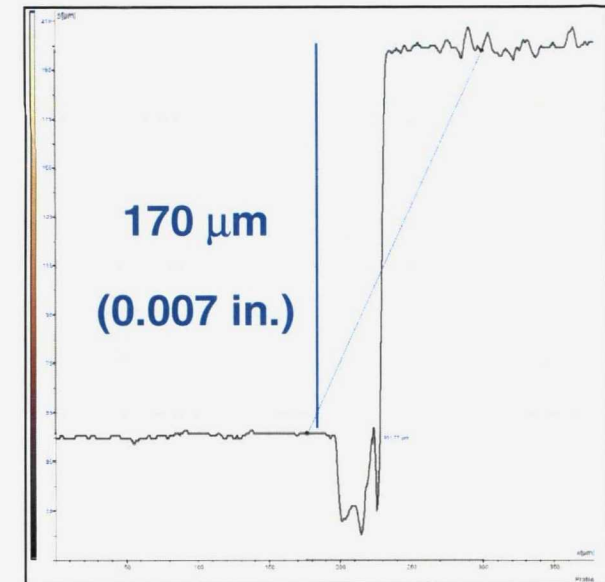
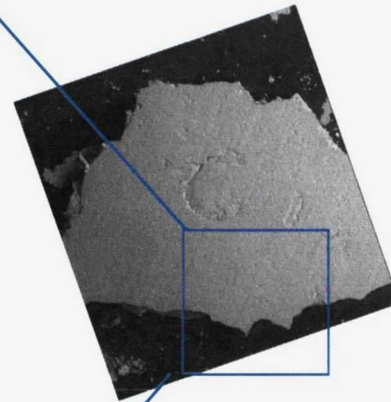


SEM images showing the 3-dimensional topography of the SARJ fragments. Note the relatively flat fracture path and the sharp, perpendicular edges.



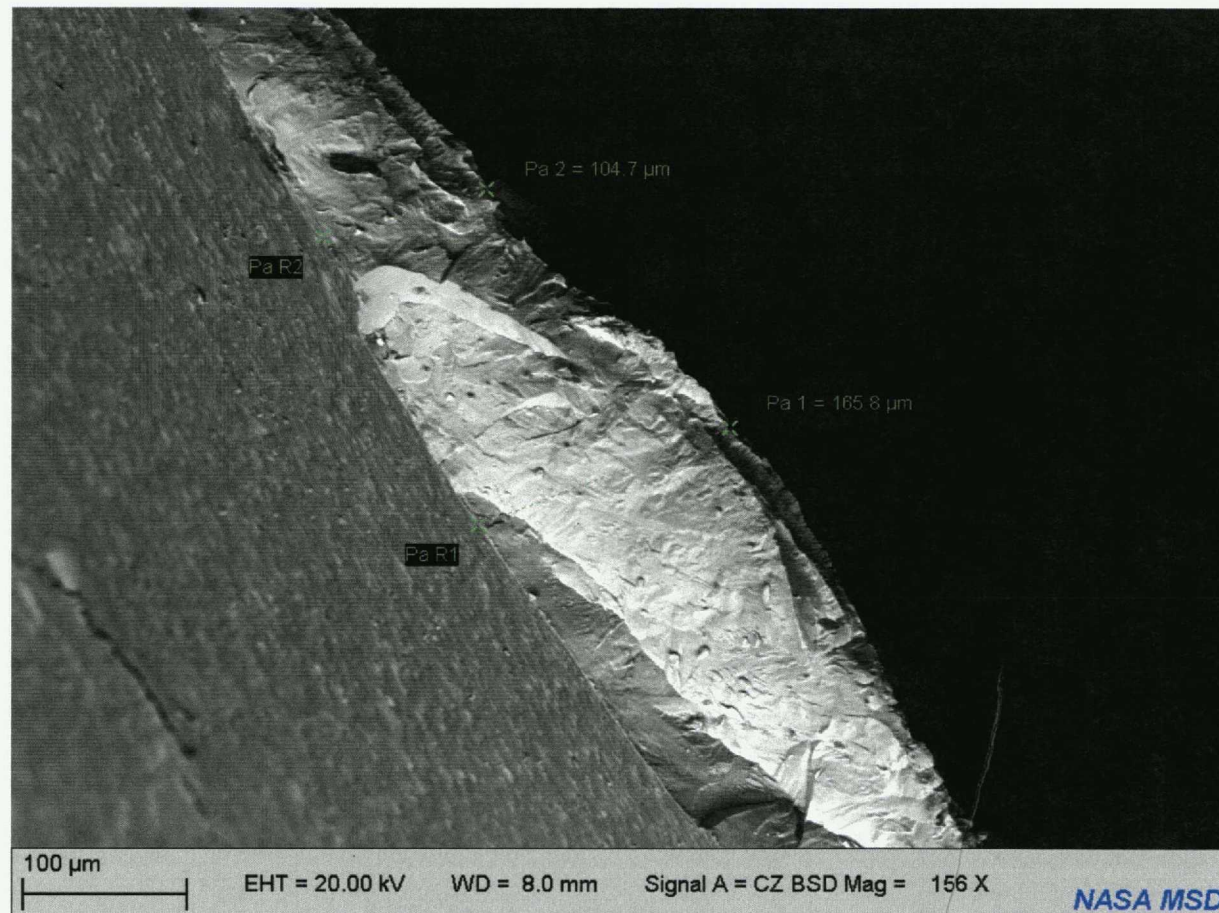


Typical confocal topographical images (2D, 3D) and resulting chart.



Confocal microscopy was used for in-situ (non-destructive) thickness measurements at 100X magnification of several particles.



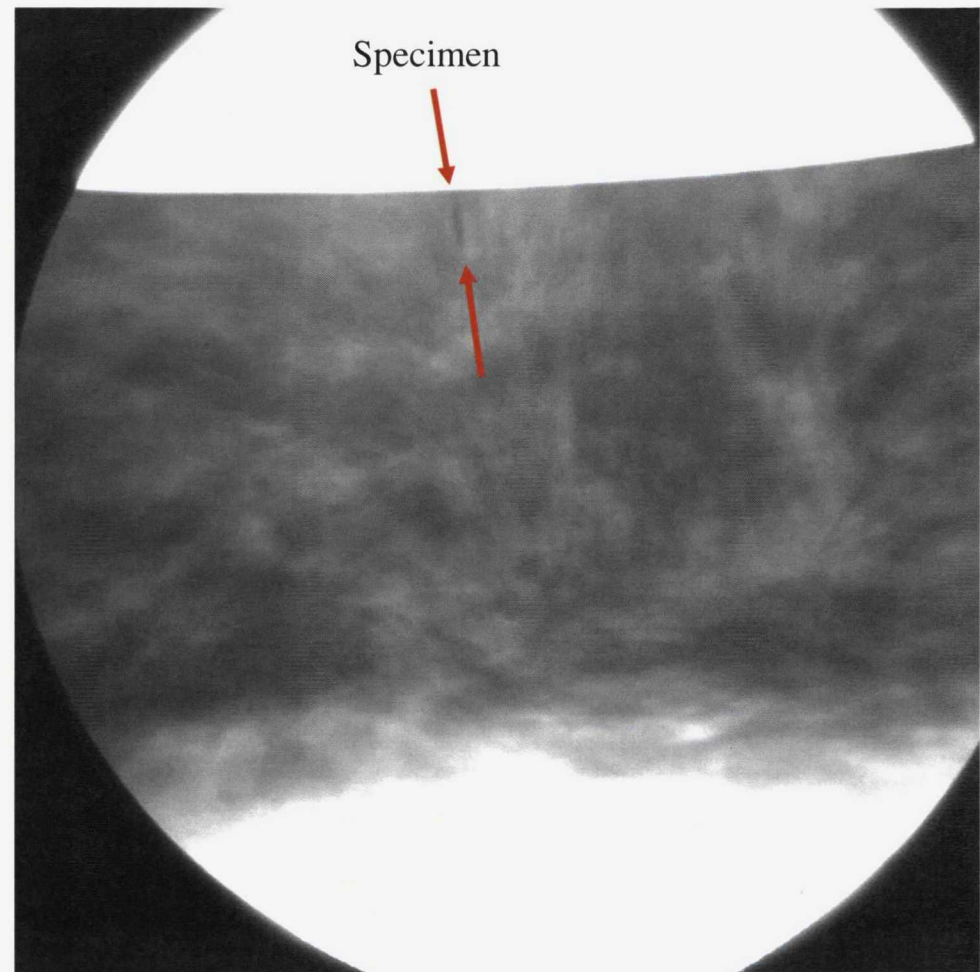


Particle thickness measurements of a large particle in the SEM correlated with measurements taken using laser confocal microscopy, which were 100 to 165  $\mu\text{m}$  for this particle.





- Specimens were ground, polished, and etched to examine the cross sectional microstructure.
- Real-time X-ray was utilized to locate the specimen in the metallographic mount and provide orientation and progress during polishing (right).

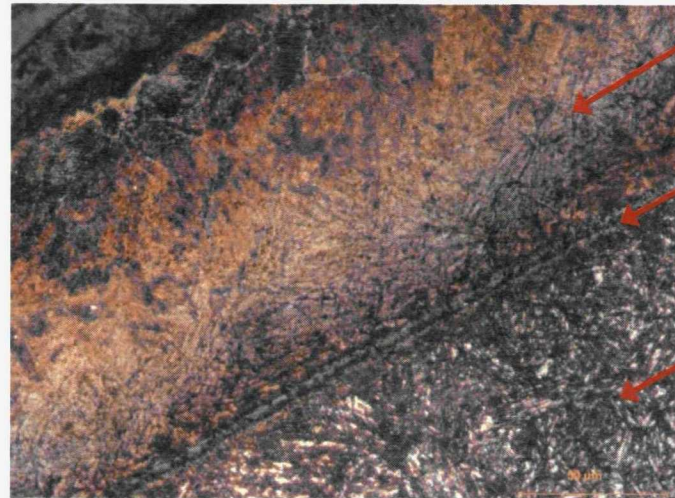






Typical nitrided  
stainless steel.

500X



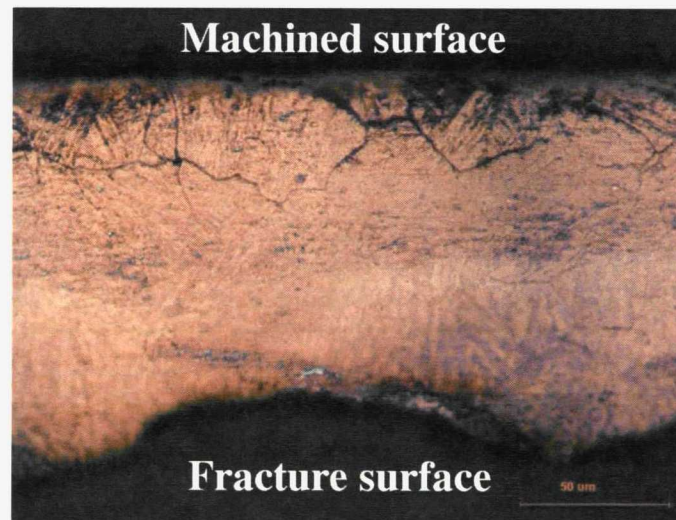
Nitrided case (120  $\mu\text{m}$ )

Interface

Martensitic core

SARJ fragment  
cross section.

500X



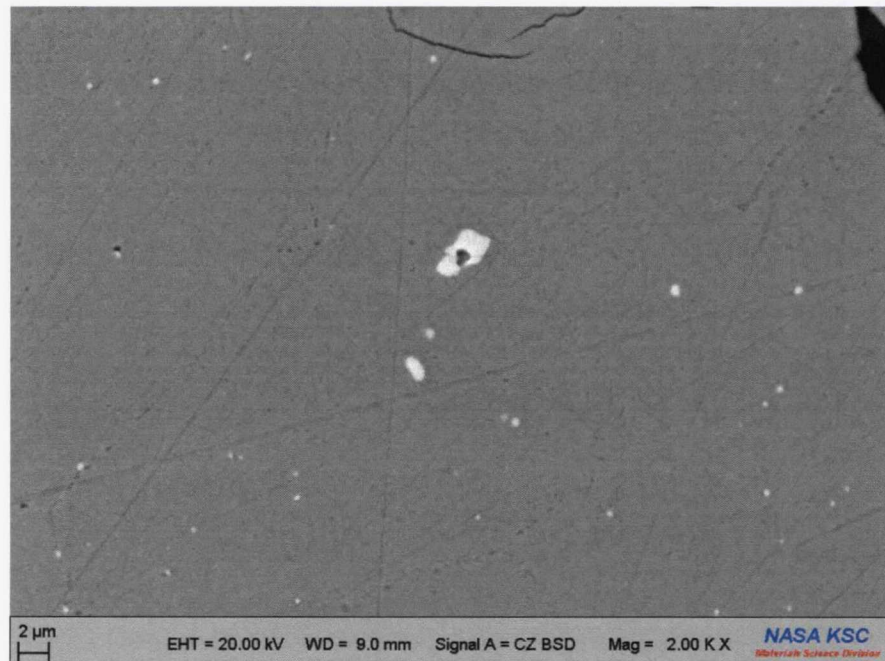
No martensitic core was  
observed in SARJ  
fragment.

Microhardness of the mounted cross section was converted to approximately 71 Rockwell C (HRC).

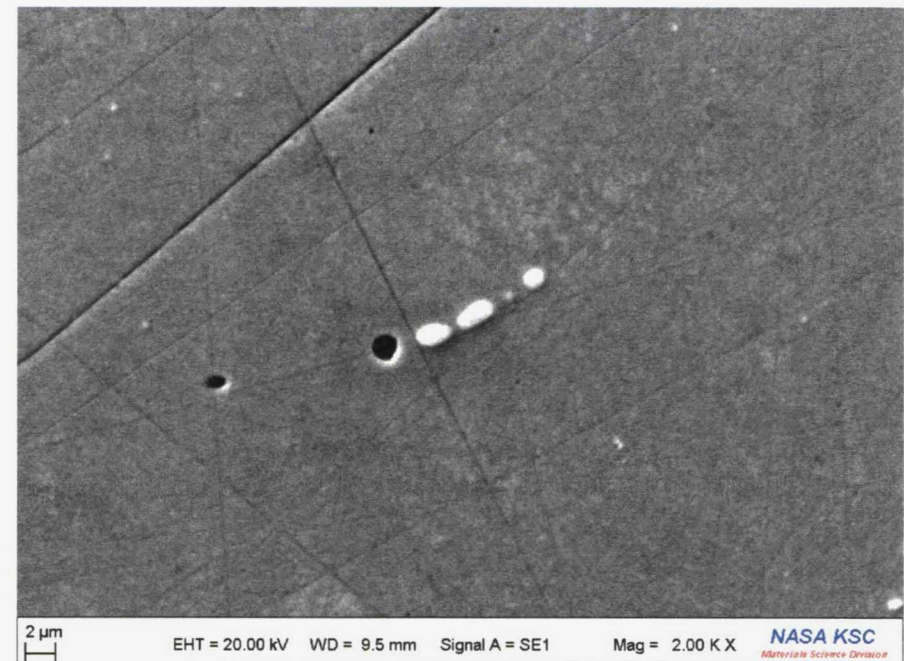




SARJ fragment



Stock 15-5PH



The precipitates in the SARJ fragment were similar in size and distribution to stock 15-5 PH stainless steel.





- Contact stress fatigue, i.e. spalling, with subsurface initiation:
  - Location of origin – “Short distance below surface, usually at a nonmetallic inclusion”
  - Initial size – “Small”
  - Initial shape – “Irregular”
  - Crack angle with respect to surface – “Roughly parallel at bottom, perpendicular at sides”
  - Apparent occurrence – “Sudden”

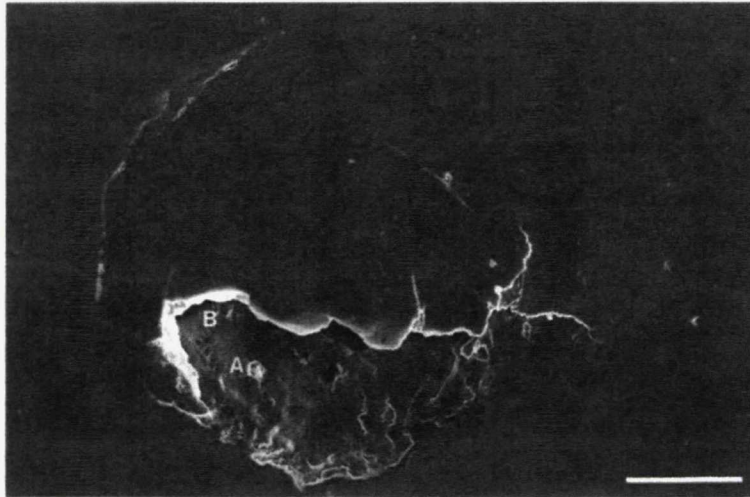
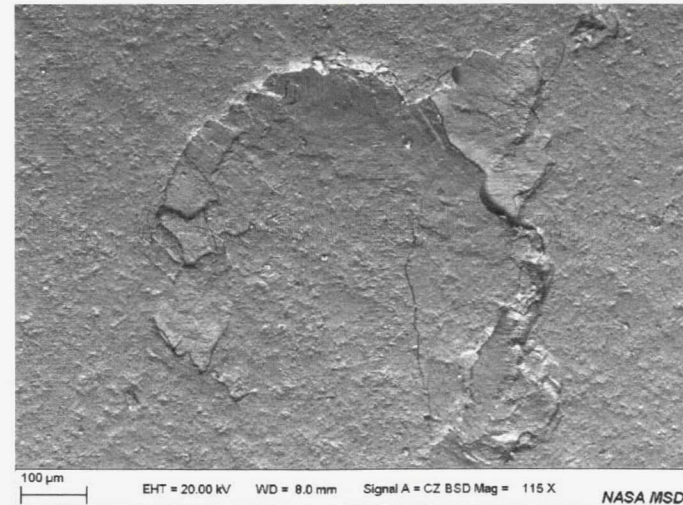


Image and text from Wulpi, D.J., *Understanding How Components Fail*. ASM International. 1985. p. 199.

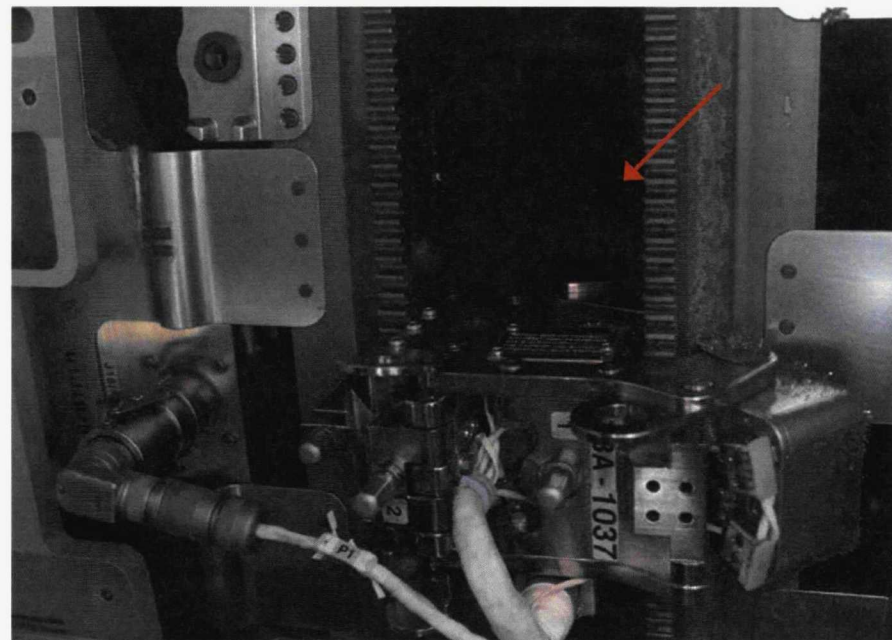
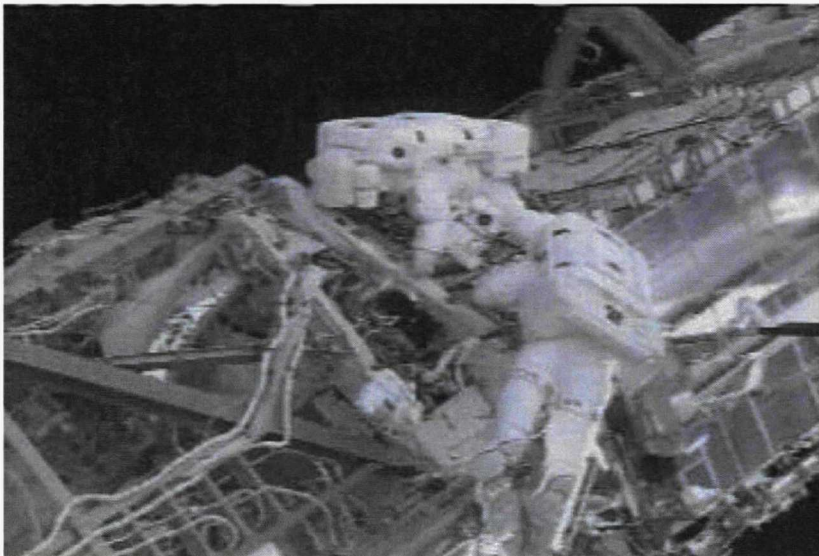


Incipient spall on the SARJ fragment



KSC Engineering Directorate  
Materials Science Division

Expedition 16, EVA 13,  
December 2007

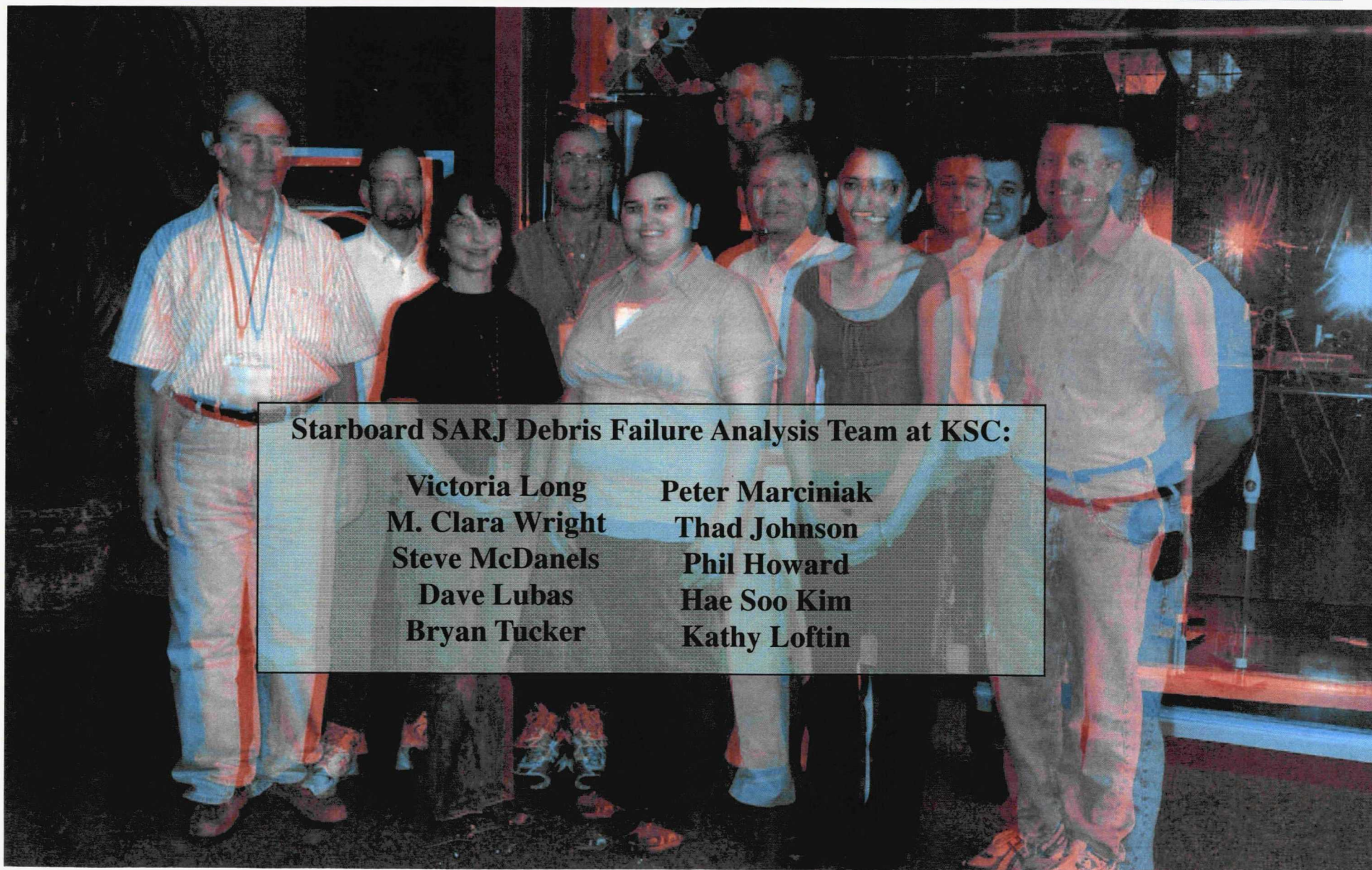






**KSC Engineering Directorate  
Materials Science Division**

**Failure Analysis Team**



**Starboard SARJ Debris Failure Analysis Team at KSC:**

**Victoria Long  
M. Clara Wright  
Steve McDanel  
Dave Lubas  
Bryan Tucker**

**Peter Marciniak  
Thad Johnson  
Phil Howard  
Hae Soo Kim  
Kathy Loftin**